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EFFECT OF AN ELECTRIC FIELD ON THE VISCOSITY OF THERMOPLASTIC CERAMIC SLIPS AND ON THE DEFORMATION OF ARTICLES ACCOMPANYING THE REMOVAL AN ORGANIC BINDER

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The results of an investigation of the effect of an electric field on the viscosity of thermoplastic slips of the ceramic VK95-1 and VF52.42-1 and on the deformation of the castings occurring when the organic binder is removed are presented. It is determined that when a constant electric field is applied the viscosity of the thermoplastic slip decreases. When the field strength increases from 10^3 to 10^6 V/m the viscosity decreases by a factor of 3. An electric field helps to preserve the shape of the ceramic casting (with no deformation) during the removal of the organic binder from it and makes it possible to decrease substantially (by a factor of 6) the duration of this technological operation.

Hot casting under pressure is widely used to fabricate ceramic articles with complex shapes [1 – 3]. Thermoplastic slips for forming articles are obtained from finely milled calcined ceramic material (cake) and an organic binder — paraffin with a surfactant (SAM) added. The regimes for hot casting of ceramic articles and removing the organic binder from them are largely determined by the viscosity of the slips obtained.

We have investigated an aluminum-oxide ceramic VK95-1 and the forsterite ceramic VF52.42-1 [4]. The slip used for the production of articles contains paraffin (mass content): 12 – 13% for VK95-1 ceramic and 10 – 11% for VF52.42-1 ceramic. In addition, a surfactant is added in both cases — 0.3 – 0.4 at.% oleic acid with respect to the mass of the cake; the acid is added at the time the cake is milled. The thermoplastic slips are prepared by mixing the milled cake and paraffin in a heated state (90 – 100°C) for 2 – 4 h with continual evacuation. The viscosity of the slips obtained at 70°C is 5 – 20 Pa · sec (VK95-1) and 20 – 50 Pa · sec (VF52.42-1).

An electric field was used to regulate the viscosity of the thermoplastic slips. The investigations were conducted with a viscosimeter (M. P. Volarovich's system) with an attachment which made it possible to regulate the field strength from 10^3 to 10^6 V/m.

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It is shown in USSR Inventor's Certificate No. 1346626 that when a constant electric field is applied, the viscosity of a thermoplastic slip decreases — the stronger the applied field, the greater the decrease is (see Table 1).

A fused thermoplastic slip is a disperse system, consisting of liquid (paraffin) and solid (ceramic particles) parts. The molecules of oleic acid $C_{17}H_{33}COOH$ are oriented with the polar groups directed toward the ceramic particles of the cake and nonpolar groups (hydrocarbon chains) are directed toward the paraffin, balancing the polarity of the phases,

TABLE 1.

Field strength, 10^{-3} V/m	Viscosity (Pa · sec) at temperature, °C		
	60	70	80
	VK95-1 ceramic		
–	25.6	17.0	11.0
1	19.6	13.9	9.9
10	17.1	12.1	8.2
100	9.5	6.7	5.0
1000	7.5	5.1	3.5
	VF52.42-1 ceramic		
–	50.4	40.1	28.7
1	50.3	38.1	23.8
10	50.2	37.6	21.8
100	7.9	6.6	4.9
1000	2.6	2.1	1.5

lowering the required amount of paraffin and the viscosity of the slip obtained. Calculations show that even when a monolayer of these molecules forms, they can cover only a part of the surface of the solid particles. In this case, ordinarily, cluster-like adsorption of the surfactant molecules on the active points of the surface of the solid occurs.

Apparently, the effect of an electric field (especially with increasing strength) is to change the distribution of the surfactant molecules, which become more uniformly spread over the surface of the solid particles. To a certain extent, this effect is similar to the introduction of an additional amount of surfactant and promotes a decrease of the viscosity of the slip. After the electric field is removed, the surfactant molecules will become disoriented and the viscosity of the slip will unavoidably increase. This process depends on the thermal displacement of such molecules and its duration is quite long. The viscosity of the slip approaches its initial value only after several tens of hours after the electric field has been removed. Experiments have shown that the viscosity of slips prepared without surfactants returns to its initial value more quickly after the electric field is removed.

Different methods are used to remove the thermoplastic binder from ceramic blanks [1 – 3]. A widely used method is to place the castings into a charge consisting of mineral powder, for which porous refractory stands can be used [3]. The slips must have a sufficiently high viscosity, so as to ensure that no deformation of the articles occurs when the binder is removed. The most dangerous periods during the heating of the castings on porous stands are when binder transitions from a solid into a liquid (50 – 60°C) and from a liquid into a gaseous state (150 – 170°C) [1, 2].

An electric field can affect the structural-mechanical properties of dispersed systems [5]. A force arises at the interface of two dielectrics with permittivities ε_1 and ε_2 directed toward the medium with the lower permittivity. In the absence of charge on the interface, which is characteristic for dielectrics such as ceramic cake and paraffin, the force arising, called the Maxwell surface tension, depends on the directions of the electric field, the electric induction, and the normal to the surface. This force is proportional to the difference of the permittivities ($\varepsilon_1 - \varepsilon_2$) and the squared strength of the applied electric field [6].

In our case — paraffin ($\varepsilon = 2.0 – 2.5$) and ceramic ($\varepsilon = 8 – 10$) — the Maxwell surface tension arising at the interface with an electric field 10^5 V/m is about 0.350 N/m, which is substantially greater than the surface tension of fused paraffin (0.026 N/m). This should prevent paraffin from spreading and decrease the deformation of the ceramic castings when they are heated during the removal of the organic binder.

The effect of high-frequency and constant electric fields was studied experimentally. An electric voltage was applied to capacitor plates separated by a distance 0.03 m. Ceramic articles were placed on supports between the plates.

A generator operating at 40.68 MHz was used as the source of the high-frequency electric fields. The maximum output power was 4 kW. The strength of the high-frequency electric field was regulated by changing the strength of the anodic current of the generator.

The results showed that for porous and nonporous supports, as the high-frequency field increases in strength the removal of the binder from the ceramic castings intensifies (USSR Inventor's Certificate No. 1315434). The process can saturate with time, especially for lower anodic currents, i.e., the amount of binder removed can reach a maximum value.

An important feature was established in the course of the experiments. If the process is interrupted at the beginning stage, when only a small amount of the binder is removed, the articles spread after the high-frequency electric field was switched off. If the process occurred for a long time and a substantial fraction of the binder was removed from the articles (40 – 50% of its total content), then the articles retained their shape, even though the paraffin in the castings was in a softened state when the binder was removed in a high-frequency field. When nonporous supports are used, substantially less binder is removed from the articles than in the case of porous supports, so that deformation in the first case was observed much more frequently if the removal of the binder was interrupted at the beginning stage.

The application of an electric field also promotes retention of shape by ceramic articles during removal of organic binder from them. In this case as well, increasing the electric field strength decreases the deformation of the articles. When the electric field is switched off during the course of the removal of the binder, the articles deform. For the same amount of binder removed, the sample in an electric field is more stable.

The application of a constant electric field makes it possible to decrease by a factor of 6 the duration of the process of removing organic binder from ceramic articles (from 12 to 2 h) while maintaining the quality of the articles and satisfying all technical conditions.

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